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Technology Survey of Small Shipyards in the Pacific Northwest

VIIIB-1

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ABSTRACT

Shipbuilding (large vessels) in the United States has undergone a dramatic change. In the past decade, a major loss of the commercial shipbuilding market became evident. While this trend of a severely shrinking industry has occurred, the importance of small shipbuilding and small shipyards has emerged. This segment of the marine industry appears to be maintaining its market share and has in some areas experienced significant increases. Although the emerging small shipbuilding and repair industry seems to be a significant part of the future of the U.S. marine industry, there are many unknowns concerning this segment of the industry.

Specific questions that exist concerning small shipbuilding can be placed in four general categories. These include (1) the current economic nature of the industry, (2) the current technical nature of the industry, (3) identification of available technology that can be used to improve the industry, and (4) research and development issues that can be pursued to improve the industry.

This paper begins to address each of these issues. Previously employed models are applied in the work. A similar survey approach was used in 1978 to address technology issues in large shipyards. This study, "Technology Survey of Major U.S. Shipyards 1978," was conducted by Marine Equipment Leasing Inc., under contract to the Maritime Administration as part of the National Shipbuilding Research Program. Its goal was to compare existing technology levels in major U.S. shipyards with foreign shipbuilding technology. The results were to be used to help direct and prioritize research and development, and technology transfer efforts to be conducted under the auspices of the National Shipbuilding Research Program.

While the basic model can be used for this work, the goal would be to compare small shipbuilding technology to existing large shipbuilding technology. Since information on existing technology in large shipbuilding is readily available, both for U.S. and foreign shipyards, the comparison required only the development of information concerning existing technology used in small ship production. The list of items to be included in the survey is based on those in the 1978 survey. In order to achieve a reasonable level of confidence in the survey results, on-site visits are required. These were performed by a single surveyor (the author) on a series of visits to eight shipyards in the Pacific Northwest.

Following completion of the surveys, the data have been compiled and analyzed. Based on these results, a description of the current level of technology application is presented and future needs in the areas of technology transfer, and research and development are identified.

INTRODUCTION

Shipbuilding (large vessels) in the United States has undergone a dramatic change in the past few decades. Following a period of rapid expansion (World War II), the industry experienced a sharp decline that was followed by a relatively stable market. That market was mixed between commercial and military shipbuilding and repair activities. Over the past decade, a major loss of the commercial shipbuilding market became evident. This was in part replaced by the expansion of military shipbuilding to achieve the "600 ship Navy." As that program is winding down, the industry has experienced an unprecedented loss of large shipbuilding market and a number of major shipyards have closed.

While this trend of a severely shrinking industry has occurred, the importance of small shipbuilding and

small shipyards has emerged. This segment of the marine industry appears to be maintaining its market and has in some areas experienced significant increases. Although the emerging small shipbuilding and repair industry seems to be a significant part of the future of the U.S. marine industry, there are many unknowns concerning this segment of the industry.

Specific questions that exist concerning small shipbuilding can be placed in four general categories. These include (1) the current economic nature of the industry, (2) the current technical nature of the industry,(3) identification of available technology that can be used to improve the -- industry, and (4) research and development issues that can be pursued to improve the industry.

This work is the first step in addressing some of these issues. The primary focus of this paper is topic 2 above. Previously employed models have been applied in this work. The study employed survey techniques and evaluations by independent experts. A similar survey approach was used in 1978 to address technology issues in large shipyards. This study, "Technology Survey of Major U.S. Shipyards 1978," [1] was conducted by Marine Equipment Leasing Inc., under contract to the Maritime Administration as part of the National Shipbuilding Research Program. Its goal was to compare existing technology levels in major U.S. shipyards with foreign shipbuilding technology. The results were to be used to help direct and prioritize research and development, and technology transfer efforts to be conducted under the auspices of the National Shipbuilding Research Program. While the basic model can be used for this work, the goal would be to compare small shipbuilding technology to existing large shipbuilding technology. Since information on existing technology in large shipbuilding is readily available, both for U.S. and foreign shipyards, the comparison would require only the development of information concerning existing technology used in small ship production. The list of items to be included in the survey was based on those in the 1978 survey. This list. however was modified to-be more applicable to small ships and small shipyards. In order to achieve a reasonable level of confidence in the survey results, on-site visits are required. These were performed by the author on a series of visits to yards located in the Pacific Northwest, primarily in or near Seattle.

Following completion of the surveys, the data have been compiled and analyzed. The goal is to identify future needs in the areas of technology transfer, and research and development. These questions were also a part of the on-site surveys and responses from operators of small shipyards were used.

DEFINITION OF SMALL SHIP PRODUCTION TECHNOLOGY

There are number of specific issues that must be addressed in defining the scope of the study. Three items must be described, including small ship, production and technology. Two of these areas are relatively easy to define, while the third is somewhat more elusive. For this paper, production is defined as any of the hardware related functions that are normally performed by shipyards on vessels, including new construction, overhaul and repair. Although the focus will be on shipyards with the potential to build new vessels, repair and overhaul has been and is likely to continue to be a major part of the business of shipyards. Thus this study will consider technology associated with any of those three types of work.

The Marine Equipment Leasing Inc. study surveyed technology in eight major categories. The categories are listed in the next section. These eight areas were further subdivided to produce 72 elements to be considered. While some of these are not applicable in this study, and others have been added in light of the developments in shipbuilding productivity research that has occurred during the past decade, they form a general bound and thus a definition of technology to be considered. It is important to note that both hardware related technology, such as cutting and bending equipment, and computers, and software related technology, such as scheduling and human resource support systems are included. Thus the definition of technology is broad and includes management, organization, engineering, and manufacturing and repair equipment and hardware. A detailed survey form, outlining all areas considered was used to conduct the survey.

This leaves only the definition of small ship remaining. Unfortunately, this definition is the most ambiguous. Rather than defining a vessel size or type, small shall be presented in terms of small shipyard. The Maritime Administration "is responsible for maintaining current records on facilities, workloads and employment in U.S. private shipyards." [2] That information is processed in two databases, the Active Shipbuilding Base (ASB) and the Shipyard Mobilization Base (SYMBA). These are:

> "The U.S. Active Shipbuilding Base (ASB) is defined as privately-owned shipyards that are open and engaged in, or actively seeking, construction contracts for naval and commercial ships over 1,000 gross tons. The Shipyard Mobilization Base (SYMBA) is defined as those facilities capable of constructing, drydocking, and/or topside repairing vessels 400 feet in length and over." [2]

The Maritime Administration listed 19 shipyards in the ASB as of July, 1989. Since then, at least one of those yards has closed. The SYMBA was considered to include 114 facilities, including the 19 in the ASB. The majority of these companies fall in the topside repair category, specializing primarily in repair work on U.S. Navy vessels. The yards in the ASB and/or the SYMBA are not the target of this research.

A list of smaller shipbuilding and repair facilities, throughout the United States, compiled in 1987 by the Maritime Administration, listed over 250 yards in this category. Unfortunately, the Maritime Administration does not consider this segment of the marine industry to be within the scope of its data collection and analysis activities. Thus, no statistical evaluation of these yards is available. [3] Although the definition is not clear, most of these companies worked primarily on "small ships," either in new construction or repair. These are the target of this study. Thus despite avoiding the issue of a firm definition of small ship, the type of yard of interest is relatively clear. Since this study is from only one geographical area, a firm definition becomes less necessary and local knowledge of the yards aids in determining those that are more involved in small vessel production.

TECHNOLOGY SURVEY

The basic categories of the survey come from the Marine Equipment Leasing study. [4] The categories are listed in Table 1 below. Table 2 shows the breakdown of the evaluation technique, including the 8 major categories, the 72 elements within the 8 categories and the 4 technology levels. The surveys included an interview with a designated representative of the shipyard, followed by a tour of the yard. The shipyard representatives were commonly the president, chief engineer or production manager. Interviews averaged two hours, with the yard tour taking about one hour. The survey form was filled out with notes and impressions. Following the completion of all eight surveys, the elements within each category were rated one at a time for each yard, using the scale of 1 to 4 and rating to tenths. Thus, a yard that was found to be applying technology in a particular element half way between "good" and "better" would be rated at 2.5 for that element. After all elements were rated for all yards, averages per element and per category were computed and are reported.

The specific data sought in each of these categories can be found in appendix B to the Marine Equipment Leasing study. The important categories based on the total survey results will be described in the results section. In addition to these technology categories, a few general questions concerning the relative size and market of the yards were included.

SHIPYARDS SURVEYED

Eight yards were surveyed, but will not be specifically identified due to promises of confidentiality. They were chosen because they represent a good cross section of small vessel production facilities in the Pacific Northwest. The average employment was 225. with the smallest employing 40 and the largest 870. Average yearly sales for these yards was about $30 million, although one yard had sales about five times this average. The yards vary in work mix from 100% repair to as much as 90% new construction. Vessel types involved include large custom designed yachts, commercial passenger vessels (including ferries), fishing vessels, usuallv between 50 and 250 feet in length; tugs, barges and government vessels, including navy gunboats, smaller Coast Guard vessels, research vessels and pilot boats. The limitation in size was primarily related to facility constraints, including water depth and haulout or launch capabilities, and work force size and mix. In general. the later limitation is economic, in that the smaller yards preferred not to be limited to one job that consumes the great majority of human and facility resources.

RESULTS AND ANALYSIS

The following series of figures represents the survey results. Figure 1 shows the averages within the eight major categories, and should be referred to during discussion of overall category averages. Figures 2-9

Table 1 Elements surveyed

A: STEEL WORK PRODUCTION
- A1 Plate Stockyard and Treatment
- A2 Stiffener Stockyard and Treatment
- A3 Plate Cutting
- A4 Stiffener Cutting
- A5 Plate and Stiffener Forming
- A6 Subassembly
- A7 Flat Unit Assembly
- A8 Curved and Corrugated Unit Assembly
- A9 3-D Unit Assembly
- A10 Superstructure Unit Assembly
- All Outfit Steelwork

B: OUTFIT PRODUCTION AND STORES
- B1 Pipework
- B2 Engineering/Machine Shop
- B3 Blacksmiths
- B4 Sheetmetal Work
- B5 Woodworking/Joiner Shop
- B6 Electrical
- B7 Rigging
- B10 General Storage
- Bll Auxiliary Storage

C: OTHER PRE-ERECTION ACTIVITIES
- Cl Module Building
- C2 Outfit Parts Marshalling
- C3 Pre-Erection Outfitting
- C4 Block Assembly
- C5 Unit and Block Storage

D: SHIPCONSTRUCTION AND INSTALLATION
- D1 Ship Construction
- D2 Erection and Fairing
- D3 Welding
- D4 On-Board Services
- D5 Staging and Access
- D6 Pipework
- D7 Engine Room Machinery
- D8 Hull Engineering
- D9 Sheetmetal Work
- D10 Woodwork
- D11 Electrical

D: SHIPCONSTRUCTION AND INSTALLATION *(continued)*
- D12 Painting
- D13 Testing and Commissioning
- D14 After Launch

E: LAYOUT AND MATERIAL HANDLING
- E1 Layout and Materiel Flow
- E2 Materials Handling

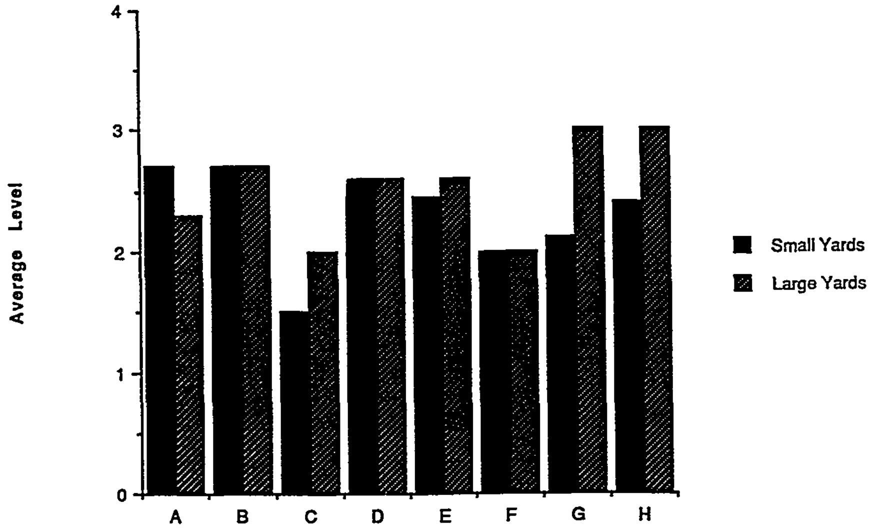
F: AMENITIES
- F1 General Environmental Protection
- F2 Lighting and Heating
- F3 Noise, Ventilation and Fume Extraction
- F4 Canteen Facilities
- F5 Washrooms/V.Cs./Lockers
- F6 Other Amenities

G: DESIGN, DRAFTING, PRODUCTION ENGINEERING AND LOFTING
- G1 Ship Design
- G2 Steelwork Drawing Presentation
- G3 Outfit Drawing Presentation
- G4 Steelwork Coding System
- G5 Parts Listing Procedures
- G6 Production Engineering
- G7 Design for Production
- G8 Dimensional and Quality Control
- G9 Lofting Methods

H: ORGANIZATION AND OPERATING SYSTEMS
- H1 Organization of Work
- H2 Contract Scheduling
- H3 Steelwork Production Scheduling
- H4 Outfit Production Scheduling
- H5 Outfit installation Scheduling
- H6 Ship Construction Scheduling
- H7 Steelwork Production Control
- H8 Outfit Production Control
- H9 Outfit Installation Control
- H10 Ship Construction Control
- H11 Stores Control
- H12 Performance and Efficiency Calculations
- H13 Computer Applications
- H14 Purchasing

Table 2 Evaluation technique

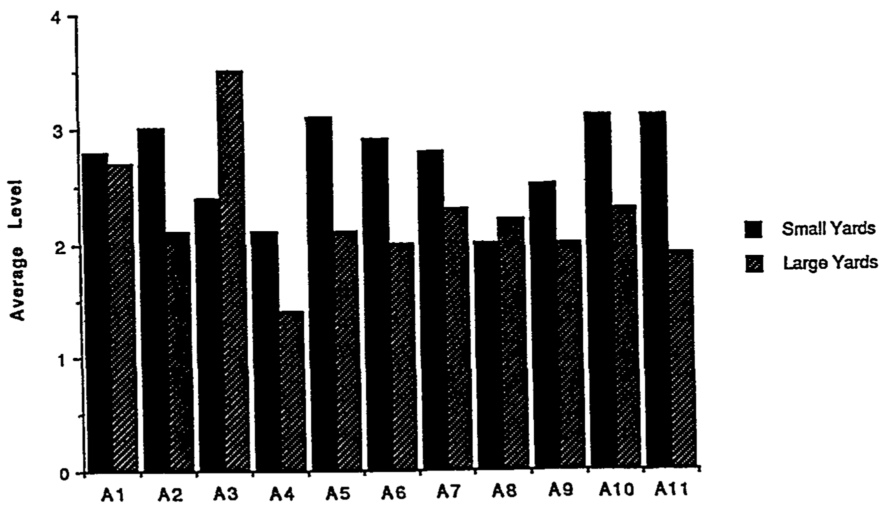
CATEGORIES		ELEMENTS	TECHNOLOGY LEVELS
A STEELWORK PRODUCTION	A1-11	C1 MODULE BUILDING	1 FAIR
B OUTFIT PROD. & STORES	B1.10	C2 OUTFIT PARTS MARSHALLING	2 GOOD
C OTHER PRE-ERECTION ACT.	C1-5	C3 PRE-ERECTION OUTFITTING	3 BETTER
D SHIP CONST. & INSTALL	D1-13	C4 BLOCK ASSEMBLY	
E LAYOUT & MAT'L. HANDLING	E1-2	C5 UNIT & BLOCK STORAGE	4 BEST
F AMENITIES	F1-6		
G DESIGN. DRAFTING. PROD. ENG'RG.	G1-9		
H ORG. & OPERATING SYS.	H1-14		
8 CATEGORIES	70 ELEMENTS		4 TECHNOLOGY LEVELS



Technology Categories

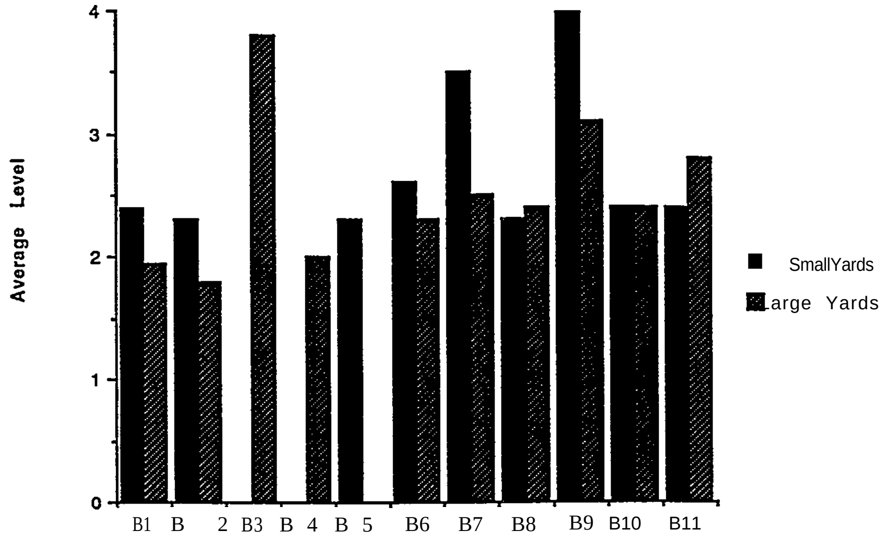
A Steelwork Production
B Outfit Production and Stores
c Other Pre-Erection Activities
D Ship Construction and Installation
E Layout and Material Handling
F Amenities
G Design, Drafting, Production
Engineering and Lofting
H Organization and Operating Systems

Fig. 1 Average Technology Levels by CategorY



A: STEEL WORK PRODUCTION
Al Plate Stockyard and Treatment
A2 Stiffener Stock and yard and Treatment
A3 Plate Cuttinng
A4 Stiffener Cutting
A6 Plate Stiffener Forming
A6 Subassembly
A7 Flat Unit Assembly
A8 Curved and Corrugated unit Assembly
A9 3-D Unit Assembly
A10 Superstructure Unit Assembly
All OutfitSteelwork

Fig. 2 Average Technology Levels in Steelwork Production



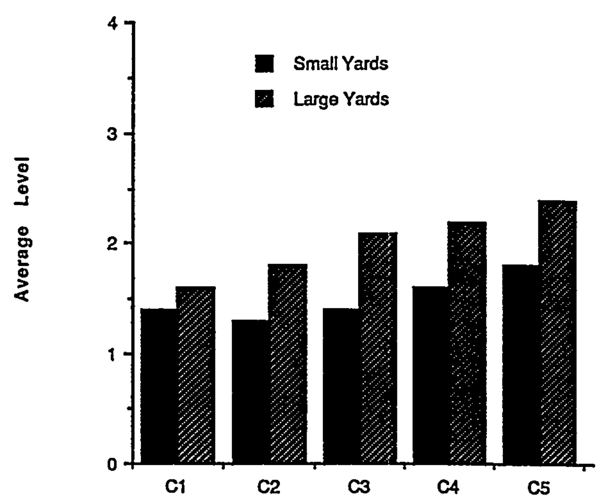
B: OUTFIT PRODUCTION AND STORES
B1 Pipework
B2 Enginnering/Machine Shop

B4 Sheemetal Work
B6 Electrical Shop

B7 Rigging
B8 Maintenance

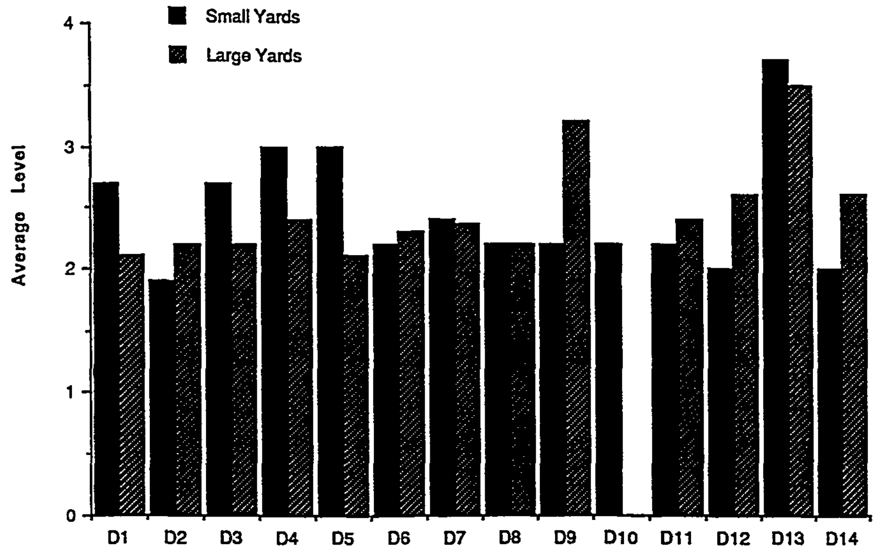
B9 Garage Storage
Bll Auxiliary Storage

Fig. 3 Average Technology Levels in Outfit Production and Stores



C: OTHER PRE-ERECITION ACTIVITIES
Cl Module Building
C2 Outfit Parts Marshalling
C3 Pre-Erection Outfitting
C4 Block Assembly
C5 Unit and Block Storage

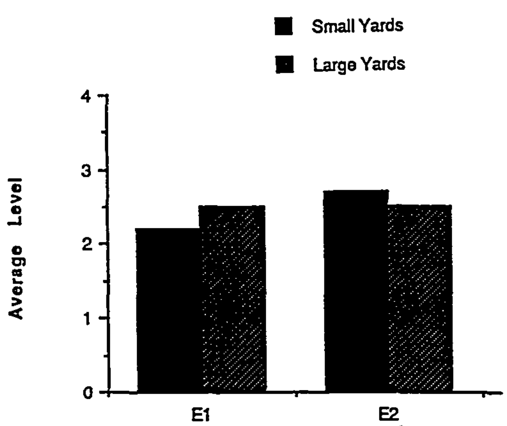
Fig. 4 Average Technology Levels in Other Pre-Erection Activities



D: SHIP CONSTRUCTION AND INSTALLATION

D1 Ship Construction
D2 Erection and Fairing
D3 Welding
D4 On-Board Services
D5 Staging and Access
D6 Pipework
D7 Engine Room Machinery
D8 Hull Engineering
D9 Sheetmetal Work
D10 Woodwork
D11 Electrical
D12 Painting
D13 Testing and Commissioning
D14 After Launch

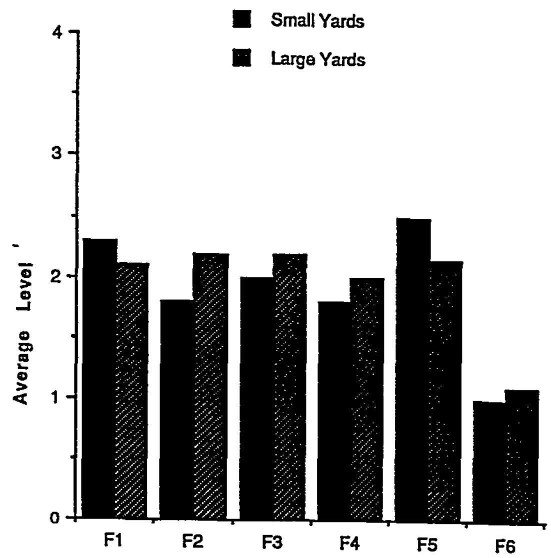
Fig. 5 Average Technology Levels in Ship Construction and Installation



E: IAYOUT AND MATERIAL HANDLING

E1 Layout and Material Flow
E2 Materials Handling

Fig. 6 Average Technology Levels in Layout and Material Handling

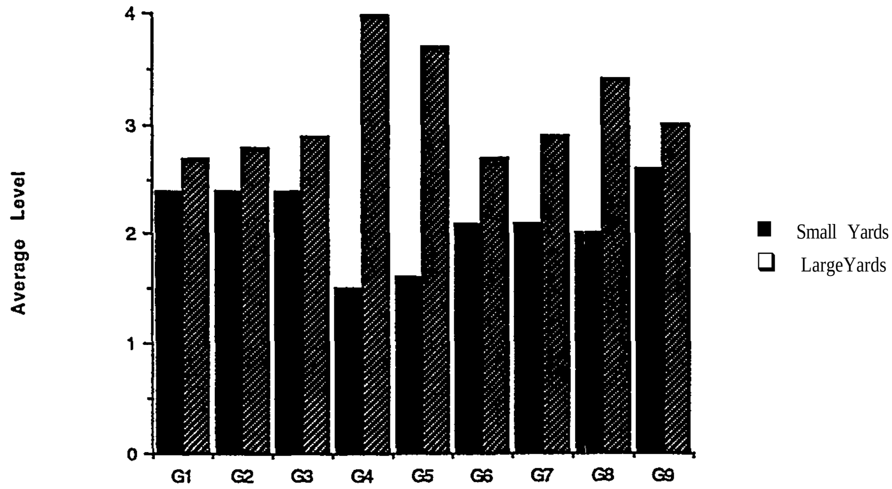


F: AMENTTIES

F1 General Environmental Protection

F3 Noise, Ventilation and Fume Extraction
F4 Canteen Facilities
F5 Wash rooms/W.Ca/Lockers
F6 Other Amenities

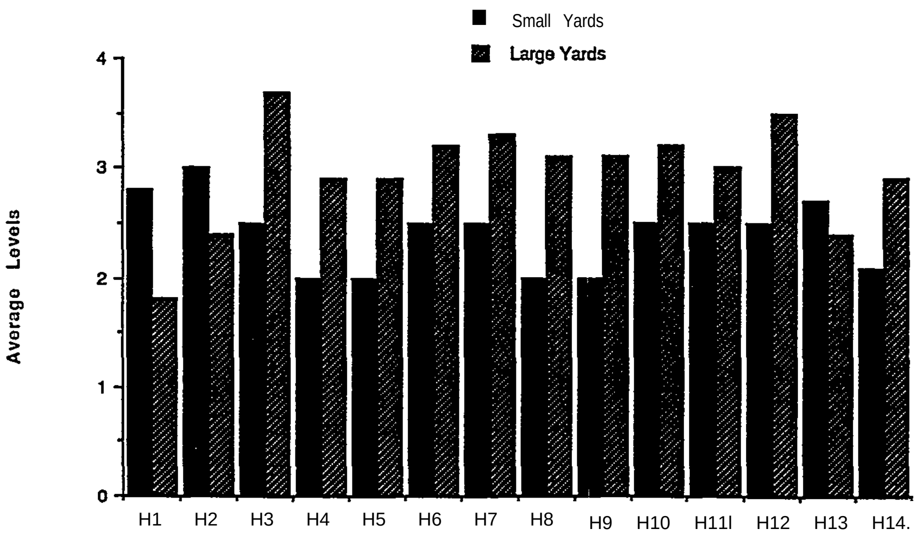
Fig. 7 Average Technology Levels in Amenities



G: DESIGN, DRAFTING, PRODUCTION ENGINEERING AND LOFTING

G1 Ship Design
G2 Steelwork Drawing Presentation
G3 Outfit Drawing Presentation
G4 Steelwork Coding System
G5 Parts Listing Procedures
G6 Production Engineering
G7 Design for Production
G8 Dimensional and Quality Control
G9 Lofting Methods

Fig. 8 Average Technology Levels in Design, Drafting, Production Engineering and Lofting



H: ORGANIZATION AND OPERATING

H1 Organization of Work
H2 Contract Scheduling
H3 Steelwork Production Scheduling
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H5 Outfit Installation Scheduling
H6 Ship Construction Scheduling
H7 Steelwork Production Control
H8 Outfit Production Control
H9 Outfit Installation Control
H10 Ship Construction Control
H11 Stores Control
H12 Performance and Efficiency Calculations
H13 Computer Applications
H14 Purchasing

Fig. 9 Average Technology Levels in Organization and Operating Systems

show the results for each of the 72 items in the eight categories, and should be referred to during discusion of categories A-H, respectively. The large U.S. shipyard ratings are taken directly from the Marine Equipment Leasing study as reported in 1980. [4] Although these do not represent current practice, they are presented unchanged to provide a basis for comparison without adding an additional uncertainty. In each case, the average level of technology application in the small yards surveyed is compared to the author's rating of the current best application in the world. Considerable documentation of the world's best technology has been accomplished under the auspices of the National Shipbuilding Research Program, including hardware and software, applied to new construction and overhaul and repair. Reports produced for that program and papers that appear in the Journal of Ship Production are the primary source. A comprehensive list of the major sources is presented in the NSRP Bibliography of Publications. [5] Although it would be possible to extend the amount of statistical evaluation of the results, the analysis will be limited to comments about each of the eight categories, and then some general conclusions.

Category A is steelwork production. In this analysis, other structural materials, such as aluminum, are also included in this category. Fiberglass was not employed as a structural material in any of the yards surveyed. The overall average is 2.7. This compares to a 1980 large shipyard average of 2.2. In this category, there has likely been substantial improvement in the large yards over this decade. The small yards exhibit relatively good technology in terms of work organization for producing sub-assemblies, and flat block assemblies. In particular, most yards build superstructures as independent structures and then land them on board. Fixed or variable (temporary) locations are often established for producing steel sub-assemblies and flat blocks. In general, these approaches are more likely to be used if more than one vessel is being built and they are commonly only applied to new construction. There is an expected weakness in plate and stiffener cutting and forming, when the work is done in the yards. However, there is a strong tendency to subcontract this work. That results in the ability of the small yard to take advantage of higher levels of technology application by the subcontractors, without having the expense of high technology equipment in the yard. These yards also commonly work on vessels with little or no curved or 3D block categories. Consequently, despite a low capability in these areas, the paucity of work required negates this as a serious deficiency.

Category B is outfit production and stores. Here again, subcontracting dominates. In particular, sheet metal, electrical, some rigging and some rolling stock maintenance are subcontracted. Category B3, blacksmiths or forge, does not apply and was not considered. The overall average for the small yards was 2.7, which compares directly with the 1980 large yard average of 2.7. For the small yards, the specific elements that were below this average (although just slightly) were pipework, machine shop work, woodwork, plant maintenance and both general and auxiliary storage. The first three reflect the general job shop work organization, i.e. a lack of the application of fixed work stations and group technology, coupled with generally older and less sophisticated equipment. The equipment is probably not a significant problem. There were a few significant exceptions, generally where a shipyard has established a specialty in order to obtain a market. A major example of this is a machine shop section set up to work on tailshafts, not only for shipyard specific work but as a subcontractor to other yards and vessel operators. Concentration in wood work is another example, both for wooden vessel repair, overhaul or construction and for cabinetry and finish work. The philosophy of the majority of these yards toward plant maintenance was somewhat short of "scheduled and planned." Instead, most maintenance was "fix it if it breaks", and only occasionally was regular scheduling of maintenance or improvement considered. Naturally, equipment that requires regular maintenance for safety regulation requirements, such as cranes, is handled as necessary. Finally, the physical storage capabilities, while generally adequate, reflect the storage philosophy, which will be discussed in category H.

The single worst category, both for small yards and in the 1980 large yard results is other pre-erection activities. The small yards were rated at 1.5, compared to 2.0 for the 1980 large yard survey. This category documents the work done away from the vessel, either pre-erection for new construction, or before re-assembly for repair and overhaul. Much of the small yard work is repair and overhaul. These activities were not included in the 1980 large yard survey. Had they been, the large yards would have likely rated closer to the current rating of the small yards. The yards, on

average, do not employ significant amounts of the best technology for improving productivity in any element in this category. Lowest ratings were given for pre-erection outfitting and outfit parts marshalling. There was no evidence of any on-unit outfitting and relatively little on-block outfitting. Parts marshalling was generally either worker or supervisor responsibility, and commonly done associated with work orders that are too large in both content and duration for effective material or production control. Similarlv. block assemblv and block storage away from the erection site are the exception. The vessel size, limiting the value of a large number of block breakdowns, and facility size constraints contribute to the lack of activity in these areas. Additionally, repair and overhaul work was uniformly treated as a one-of-a-kind job. Consequently, no formal work rationalization, leading to repeatability was evident. A result of this is on the spot planning of work, which precludes the accomplishment of any significant amount of work away from the vessel.

Category D includes more effort than should be required because of the lack of pre-erection activities. The small yard average is the same as the 1980 big yard average, 2.5. There is considerable variation within the elements in this category. Hardware related elements generally scored well. These include welding, on-board services, and staging and access. As might be expected, the level of technology application in these hardware items is not as high as in large shipyards, but the level appears to be generally appropriate given the type of work and investment capability of small shipyards. Also, the erection process and testing and commissioning procedures rated quite high. The remaining categories, relating to on-board outfit and painting work, generally rated low. The great majority of this work occurs on-board, usually after access is greatly limited. Coordination between outfitting activities is commonly scheduled by a project manager, usually on a daily or weekly basis, with relatively little pre-planning. There is no indication of any planning before design, and coordination of subcontractors did not seem to include consideration of the impact of that work on the overall productivity of the project. A small yard advantage, to be discussed in relation to category H1, is the combination of work skills in individuals or small work groups. Thus, the various types of outfit work get some de facto coordination since the same people are involved in performing the work. The small yards, like the large ones, show poor performance in erection and fairing practice, with no modern dimensional control and margins provided for erection site fairing. Here again, the job shop mentality leads the managers away from techniques that might improve productivity. Line heating as a regular distortion removal tool was not in evidence, although the use of heat for fairing and after erection distortion removal was observed.

Yard layout and material flow for small yards is generally acceptable (category E). Size is a definite advantage here. In most cases, the yard layout and material flow has developed over time, usually without an overall plan as a goal to be achieved. Additionally, most small yards have grown around existing buildings, that are not moved or replaced to improve overall flow. Thus there are some constraints and lack of planning evident, but, despite the lack of formal technology application, no major problems were identified in this category.

Category F deals with the work environment and amenities provided for the workers. Both the large and small yards score poorly in this category, 1.9 for each. This seems to be a feature of U.S. shipbuilding. The best scores are for basic personnel services, including washrooms, w.c.'s and lockers. The provision of protected work spaces, with good lighting, heating and ventilation is not common practice. The general work organization, concentrating work on-board, is in part responsible for this outcome. Where protected work spaces exist, the work environment provided is appropriate. In the Pacific Northwest, protection from rain is useful, but substantial heating is not required. Thus, subject to improving work organization, current work environment provisions seem appropriate. The small yards tend to provide almost no company wide outside activities. These functions seem less required, however, *given* the small size of the work force. Company culture, however, seems quite apparent in these shipyards. Employee loyalty seems to respond more to these company culture patterns, associated with the working environment. Thus additional formal amenities outside the working conditions would not seem to be required to achieve a satisfied and contributing work force.

Category G is an extremely critical one, and one in which current technology application and future directions are quite different between small and large yards. The average rating of 2.1 for the small yards is considerably below the 3.0 given to the

large yards in 1980. Additionally, there is an extremely wide variation between the small yards surveyed. Among the major differences is the size of the design staff and the related philosophy of how design is accomplished. The variation here is from a single owner/engineer as the only technical employee to a complete in-house design and engineering staff, with all levels of staffing in between. Related to this is the type and detail of design and engineering information that is employed. These are two related but independent considerations. For example, incomplete and inadequate engineering information can be the product of an in-house or external engineering effort. The opposite can also be true. Thus the critical factor is the determination of what and how information is developed and communicated. On average, ship design capability and drawing presentation rated 2.5 for the small yards. This level seems appropriate for the markets served. Similarly, lofting capabilities, either in-house or from a subcontractor are generally acceptable, with a clear trend to greater direct generation of lofting information from computer aided design (CAD) systems. The remaining elements, including standardization of information presentation (coding and parts listing), production engineering, design for production, and quality control rate no better than 2.1. There was no apparent movement toward planning before design, i.e. formal production input before design. Similarly, production engineering is only informally applied as seems appropriate for a particular job. Flexible standards are not evident in the small yards, unless a series production effort is underway. Additionally, the quality philosophy applied, like that evident in most large shipyards is the archaic approach of after production quality assurance, rather than in-process and pre-process quality control. These changes in corporate culture are independent of company size.

The final category is organization and operating systems. Here again, the small yards rate considerably lower than the 1980 large yards, 2.4 versus 3.0. Within this category, the elements for which the small yards rate well include organization of work, contract scheduling and scheduling and control of steel work. Although there is some variation, the major consideration in rating organization of work is the ability of the work force to combine work categories in a single worker or work team. Due to size, most small yards surveyed employ multi-disciplined work teams. Work rules, even in union shops, did not appear to constrain effective organization of work. As mentioned previously, planning is the constraint. Additionally, all the small yards surveyed did effective master scheduling. Below this level, however, only steel work schedules tended to be produced in enough detail to aid in production control. As in many other shipyards, outfit work is considered after steel work, not coordinated with steel work. Control and scheduling below the master schedule level is generally heavily dependent on the project manager. While this is generally effective in terms of completing a project, it makes company learning and improvement difficult. Similarly, since detail planning and scheduling is performed by the project manager while the work is underway, performance and efficiency calculations are general. In most cases, these were the traditional "black book" numbers maintained by the president or chief estimator. While these are effective for some types of projects, they make estimating new or different work extremely risky. As discussed in category B, facilities for storage of stock and auxiliary items were generally adequate, given the stores philosophy employed in the yards surveyed. Standard stock items are commonly monitored and ordered by the shop involved. The standard low level order point system with a fixed (economic) order size is used. No control beyond this is common. Allocated stock items are commonly ordered by the project manager, or supplied by the owner. Storage is usually in a separate location, on a project by project breakdown. No use of early material identification procedures or an allocated stock category was evident in the surveys. Nearly all yards indicated the traditional difficulties imposed by uncertainty and delay in the receipt of material. Most of the smaller yards use computers adequately, including payroll, some CAD applications, some scheduling applications and some material applications. Computer capabilities, however, are available far beyond the average application in the small yards. Finally, purchasing systems are generally poor, with little repeatability and typical late delivery and expediting problems. This item is closely related to stores control, as described earlier.

CONCLUSIONS

There are a series of general conclusions that can be drawn about technology application in small shipyards. Hardware technology is generally at a lower level than in big shipyards. This is partially evident

from looking at categories A and B, although this deficiency is largely overcome by the extensive use of subcontractors and by arrangements with vendors. For example, relatively little advanced plate cutting and forming capability exists in most of these yards. However, subcontractors are used to provide numerical control (N/C) cut steel, where a significant number of steel parts are needed. Steel is generally received already wheel-abrated and primed, and thus no facilities for performing this work are found. Also, the vessel size and typical design (hard chine and developable surfaces predominate) constrains the development of facalites for forming and assembling blocks by problem category. The curved block and 3D block categories employed for large vessel construction do not apply for small vessels. Most of the parts fabrication and assembly for outfit is also subcontracted, including sheet metal, joinery, and electric work. ten painting is subcontracted. As mentioned, a major exception is the development of a specialty in certain processes, such as tailshaft repair, woodwork, etc. These hardware constraints do not seem to be a major impediment to the improvement of productivity. In fact, substantial use of subcontractors can provide a significant advantage in lowering overhead and capital requirements, and in providing a means of responding to workload variations. However, scheduling and control of the subcontractors is a critical piece of the manufacturing system and must be carefully managed to obtain maximum benefit.

Although varying amounts of understanding of group technology or zone oriented approaches was exhibited, the "opportunities" for the application of this approach are considered to be limited by these yards. Construction or replacement of superstructure, including wheelhouses, is often done using a zone oriented approach. This is generally the most extensive application of this technology. The use of on-unit and on-block outfitting is far short of what is possible. The possibilities of applying this technology for those yards doing new construction seem quite apparent. Zone outfitting approaches, while primarily documented in applications of large ship construction, offer significant productivity improvements in any project in which complicated work in a congested area leads to competition for space in which to work. [6,7] Clearly small vessels meet this criterion, and proportionally exceed the benefits that accrue in larger shipyards.

There are three prerequisites to the application of zone technology in small shipyards. These prerequisites are the same as those required for large shipyard application of zone technology. These include the establishment of a product work breakdown structure (PWBS), the involvement of the yard in determining and obtaining sufficient information to adequately plan and control the production process, and the adoption of shipyard specific flexible standards. [8]

First, the yard managers must "conceptualize" a product work breakdown structure. Large yards have the luxury of introducing a PWBS by physically establishing work flows for the various work categories. Small yards probably cannot afford the space associated with this physical rearrangement. Thus a "conceptual" PWBS would imply a typical work flow that is organized by problem category for each job. Some work would be real flow and some virtual flow, organized to fit into the facility. Although some variations would occur based on the project, the conceptual framework of the work organization should be documented, repeatable and recognizable.

The second prerequisite involves information generation and management. Currently, technology application in these management areas, including design, scheduling, production control and material control is at a relatively low level. The choice of how to improve these areas is not easy, however. Most small yards have relatively few people that participate in these management functions. This results in both low technology utilization and low overhead costs. The most common number of design engineers in the yards surveyed is one or two. Thus much design is done by outside naval architects. The ability of a small yard to become involved in the development of a build strategy as part of design is thus a function of the understanding of zone logic on the part of the naval architect, the owner, and the yard naval architect. This has often resulted in little input from the yard during design. Instead, yard process and design preferences are generally only considered after selection of the yard by the owner and then during contract negotiation or after the contract award. The opportunities for the development of a build strategy are therefore severely limited. [9] Thus a new approach is required. One possibility is an extension of the use of subcontractors that has been effectively applied in production. In this case, the subcontractor would be a naval

architectural firm. However, the arrangement must be more like that employed in hiring a production subcontractor, where the shipyard develops a relationship with the naval architectural subcontractor, including maintaining information about yard capabilities, preferred build strategies, etc. This service should not involve any conflict of interest concerning the naval architect also working for an owner, with the possible exception of that naval architect also being an owner's representative during production. While such an arrangement would require careful consideration on the part of all parties, long term benefits would be obtained by owners, shipyards and naval architects. An important aspect of this system would be documentation of build strategegles for the yard. Competition would, then be for a vessel with given capabilities, that would be achieved by slightly different designs tailored to shipyard specific design details. As always, price and schedule would be the main decision variables. This system would reduce the costs associated with the current procedure of independent design, bids on a contract design package, negotiation between a yard and an owner, and then development of working drawings. [9] Naturally, those small shipyards that currently have in-house naval architectural capabilities can employ that capability to develop build strategies before design for new projects.

Availability of production planning and scheduling, especially before design begins, is uncommon. Planning and scheduling rarely goes beyond a key date master schedule. Ship superintendents then develop plans and schedules in daily or weekly meetings with production supervisors. Progress and cost returns are rarely developed in a formal manner, and thus this type of data commonly only resides in the "black book" of the experienced shipyard manager. A system that develops and maintains this type of information is essential to monitoring and improving productivity, with the ultimate result being lower cost, a more competitive shipyard and more accurate cost estimates. [9] The use of productivity indicators has proven to be an effective means of maintaining this type of data base. [10] While there will be some added cost associated with the implementation of such a system, its use will reduce cost and require less effort than is currently expended by the traditional superintendent/project manager driven system.

The third prerequisite deals with the material purchasing and control systems in these yards. Small yard technology application here also lags behind better marine practice. Since the most competitive shipbuilders concentrate on material control as a critical part of the management process, this is an area of considerable concern. Simple inventory and material control software systems can be employed easily and efficiently, if work is controlled repeatably through the application of a PWBS. A proven technique for obtaining control over material and design is through the adoption of shipyard specific flexible standards. [11,12] Here again, a subcontractor type relationship with a naval architect can aid in the development of such a series of standards. The establishment of a system of shipyard specific flexible standards is a data intensive effort. Use of CAD capabilities can greatly facilitate the use of standards. The achievement of such a file for small shipyards is not likely to occur quickly, but with adequate computer hardware or a naval architectural subcontractor relationship, flexible standards can be achieved over time.

To this point, much of the discussion in this section has its most obvious application in new construction. When consideration of repair and overhaul is included, the common response is "every job is different." To the contrary, recent documentation is showing the applicability of these concepts to repair and overhaul. [13,14,15,16] Since this part of the business is so critical to most shipyards, extension of the PWBS to repair and overhaul in small shipyards is a critical step to improving competitiveness. Current thinking concerning the application of a PWBS to repair and overhaul is that it is certainly effective if design/engineering effort is required. Whether such a work organization is optimum for "regular" repair work is as yet unproven.

Small yards do exhibit better worker organization than larger U.S. shipyards. Both union and non-union yards employ flexible work arrangements, including multi-skilled work groups and multiple craft workers. This capability is primarily used in on-board work, both for installation and repair. This more flexible approach to work rules offers significant productivity enhancing opportunities. The achievement of this flexibility in work is a major advantage for small yards, achieved through the excellent management efforts of small yard operators. Combined planning of structural and outfit work would greatly increase the ability of small yards to take

advantage of this flexibility in work organization.

There are a few additional items uncovered in this research that are worth noting. An area of interest and concern that was not specifically covered in the surveys, but was mentioned in many of the interviews, is the impact of environmental protection requirements. While all small shipyard managers indicated an understanding of the needs and the inevitability of increasing requirements, most felt that a means of sharing the burden associated with improvement here would be required. A second impression, mentioned previously but worth repeating is the increasing trend to subcontracting. In the long run, small shipyards could become assemblers and launchers, with the remaining work all being done by subcontractors located away from the expensive and generally prime waterfront property occupied by shipyards. This trend is apparent worldwide, and involves large and small shipyards. An inescapable conclusion associated with this trend is the increasing shortage of skilled shipyard workers. Given the poor prospects for job security, the inability to attract a significant number of new trainees is not surprising. It is disturbing, however, for if the industry is to survive, a trained work force is essential. Thus both training programs, and a commitment to the survival of the industry are required. The most important commitment to survival most come from the industry itself, by demonstrating substantial and continuing productivity improvement. Only then can a viable base be established and sustained.

Finally, all. the small yards that were surveyed are successful shipyards. Most have been in business for many years, usually at least 30 years. They are run by talented, dedicated shipbuilders. But they are all aware of the difficulties faced by the marine industry in the U.S. and all have experienced difficult swings in workload. It is with some humility that the author offers the above suggestions. The goal is to stimulate thought, discussion and analysis of different approaches that should be considered as a means of strengthening and improving the small shipyard segment of the marine industry and hopefully the entire marine industry.

FUTURE RESEARCH AND TECHNOLOGICAL NEEDS

The conclusions section above provides a series of suggested areas to be considered by small shipyards as a means of improving productivity and competitiveness. None should be tried without studv of costs and potential effectiveness. Initially, a more complete sample of small shipyards throughout the U.S. would be required to indicate the generality of these findings. While informative, a sample size of eight of perhaps 250, representing only one geographic region, is certainly not conclusive. Additionally, more than a single surveyor and analyzer might add further weight to these findings.

A primary suggestion is the establishment of a PWBS for small shipyards. The initial suggestion is to employ a "conceptual" PWBS. This suggestion certainly begs for further definition and study. Research sponsored by the Maritime Administration enabled the first two large U.S. shipyards to implement a PWBS. A similar program for one or a consortium of small shipyards would seem prudent. Similar public documentation and information transfer would be an essential part of any such approach.

The goal of enabling small shipyards to develop a build strategy and therefore plan before design was also recommended. While there is a body of experience in this approach developing in large vessel construction and overhaul, here again further consideration of the level and details of the effort needed for small vessels and small shipyards is required. Part of the effort for large shipyards involved not only internal learning, but also understanding of the new approach by owners. Experience of some owners in dealing with Japanese shipbuilders facilitated some of this requirement. Most small vessel owners do not have similar overseas experience, and thus the effort will be more significant in providing an understanding of shipyard and owner needs in this new approach. Additionally, there is considerable need for an in depth study of the implications of the long term naval architectural subcontractor relationship proposed. Technical, financial, and perhaps legal considerations must be investigated. In this area, research could be performed to develop a build strategy, block breakdown, typical outfit units, etc. for a generic small vessel design. Such an effort would provide documentation of the type and quantity of outputs required for small shipyards.

The issue of standards for the U.S. shipbuilding industry is still in need of substantial action. Of primary importance is the idea of flexible standards involving outfit units, such as those described in [12]. Standard

items are of considerably less value in improving productivity. CAD development is the major requirement in this area. While computer capability certainly exists, programs that maximize the effectiveness of flexible standards are not common practice. Work in this area may involve some basic research, but more likely can be accomplished and distributed by a demonstration project. This use of the CAD system offers a critical productivity improving opportunity.

Material definition, purchasing and control are critical parts of any effective manufacturing system. Given the difficulties with the marine supplier base, these systems become even more critical. Little new research is needed here, since proven approaches for all of these aspects of material management are available and applied in many industries. These systems can help deal with supplier and material availability problems. There is ample software, that runs on personal computer size machines, available to aid small shipyards. Thus only a technology transfer effort is required to achieve improvements in this area.

Finally, the extension of product orientation to repair and overhaul remains a critical research product. On-going work has begun to describe the principles of a PWBS for large ship overhauls. Extension of this work into small vessels and into repair of all size vessels is an important next step.

Concerning the two conclusions that were not directly sought in the surveys, some clear research requirements emerged. While there are already considerable efforts underway relating to responding to the need for environmental protection (in particular in NSRP Panel SP-1), there will undoubtedly be continuing research requirements. Additionally, training programs coupled with attempts to attract new trainees to the industry are needed. Here again, efforts are underway (NSRP Panel SP-9). The commitment to productivity improvement must come from each shipbuilder. As a first step, a self evaluation of current status using the elements of the survey would be valuable. Familiarization with the NSRP literature is also a useful beginning. Reversing the downward slide of our industry is a worthy but difficult task, requiring thinking in the long term and employing new approaches.

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